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Analysis

GHG Emissions and the Rural-Urban Divide. A Carbon Footprint Analysis Based on the German Official Income and Expenditure Survey☆

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ABSTRACT

Will climate change be mitigated automatically by ongoing processes of urbanization as proposed by the "dense cities" hypothesis? Our answer is based on the German official income and expenditure survey (EVS) of 2013, which allow us to disaggregate total household expenditures into 44 consumer good categories (COICOP) and their respective GHG intensities. Results show that the density effect of cities saves some greenhouse gas (GHG) emissions in Germany, but singularisation of households, higher incomes and greater consumption opportunities in cities work in the opposite direction. Thus, smaller and larger municipalities are more or less on par with each other in terms of per capita emissions. Rural households are found to be more affected by environmental taxes which are imposed on direct rather than on indirect energy use in the course of German "Energiewende" policy reform. This is discussed in the article as a rural-urban social equity problem.

1. Introduction

On a per capita basis, it may be that city dwellers produce less carbon emissions than their suburban peers, since they live in smaller apartments and commute smaller distances. For that reason, cities have been praised recently in popular accounts as ecological salvation (e.g. Glaeser, 2011b). While it sounds plausible that cities may save GHG emissions on a per capita base as due to their density, we ask: how strong is this effect really? And what about counterbalancing effects such as higher incomes which usually come along with urbanization (Poumanyvong and Kaneko, 2010)?

These questions are addressed in a burgeoning literature which has analysed the rural-urban carbon footprint divide in many countries and with different methods (for an overview see Schubert and Gill, 2015). For Germany, as far as we are aware, there have been no studies conducted on this issue. This is surprising given that the German government has established an ambitious energy transition program to withdraw from the use of fossil fuels as well as from atomic energy and to reduce GHG emissions by 80% until the year 2050 (Strunz, 2014). This "Energiewende" program, which in many parts of the world is observed as a challenging transition, involves different forms of taxation on energy use, mainly for private households, while energy intensive industries are considerably less burdened out of fear that they may lose their edge in global competition (Ekins et al., 2011; Habla and Roeder, 2013). As far as the density hypothesis is true, this would imply that rural households consume more household energy and gasoline and therefore are hit harder by environmental taxes than city dwellers. This distributional equity issue may jeopardize the up to now rather strong support for the environmental reforms in relevant parts of the German population.

To address these questions, we have based our analysis on the most current German official income and expenditure survey (EVS – collected in 2013) which is generally used to study the welfare impacts of economic change and policy reform. Our decomposition of consumption categories in the EVS shows that direct GHG emissions from private household and private transport energy expenditures are mainly determined by apartment size and car ownership, which show considerable urban-rural variations. At 43%, they represent a major share of total emissions and are affected directly by environmental taxes on energy prices, whereas 52% are indirect emissions from consumer goods and overhead emissions for capital investment, which are less impacted by taxation. The remaining 5% are attributed to government expenditures. The indirect emissions are mainly driven by available income which tends to be higher in cities, particularly in cities larger than 500,000 inhabitants.

This article contributes to the existing body of knowledge in three

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specific ways. First, being based on the carbon footprint method of consumer goods, it tests the density hypothesis for Germany (cf. Schubert and Gill, 2015). Secondly, in contrast to other carbon footprint studies, our article looks in closer detail at settlement patterns in conjunction with household composition, income effects and consumption opportunities, which may counterbalance the savings from density. Thirdly, by combining social and environmental data, particularly income elasticities and carbon intensities, the paper takes a much closer look at the social implications of environmental policies than has been done in many other carbon footprint studies.

The remainder of the article is divided into five sections. In the successive part, it builds on existing literature to derive testable assumptions; in the third part the data used and methods applied are described. Results are presented in part four and are discussed in part five. In the concluding section, we summarize the results and discuss possible policy recommendations.

2. Theory: GHG Emissions and Urban Settlement Patterns

In recent years the consequences of urban living for the environment have attracted increased attention in environmental research. Studies find that cities exert disproportionately high environmental pressure in terms of waste and emissions in relation to their spatial extension. When compared to a per capita basis, however, this picture might change (Dodman, 2009; Hoornweg et al., 2011a). The environmental advantages of cities in per capita terms have been subsumed under the "compact" or "density effect" hypothesis. But to what extent do GHG emissions depend on urban or rural settlement patterns and which causal mechanisms have to be taken into account? The discussion of existing literature and the derivation of our assumptions is divided into three subsections: density effects, which should result in carbon savings in the larger municipalities (Section 2.1); countervailing effects such as lower household size, higher incomes, and more consumption opportunities in cities (Section 2.2); and the specific vulnerability of rural households for higher energy prices (Section 2.3).

2.1. Density Effects Reduce Direct Per Capita GHG Emissions

The density effect refers to the benefits which accrue as a consequence of densely populated areas with a large share of high-rise, compact apartment living (Norman et al., 2006), shorter transport distances and more developed public transport (Rau and Vega, 2012; Anderson et al., 1996; Kenworthy and Laube, 1999). Several studies demonstrate the existence of per capita emission reductions in high-density urban cores due to savings in domestic energy consumption and transport services (Hoornweg et al., 2011b; Schubert et al., 2013). More compact building structures reduce the surface-area-to-volume ratio, and with it the loss of energy (Glaeser, 2011b). Similarly, network infrastructures like public transport and district heating, which are only cost-efficient in high-density urban areas, reduce carbon footprints by providing substitutes to private car use or more carbon-intensive fuels for heating (Dodman, 2009; Poumanyvong and Kaneko, 2010). This is especially the case where dependency on private transport in suburban and rural areas puts pressure on per capita emissions and, therefore, is one of the main determinants in carbon footprint analysis (VandeWeghe and Kennedy, 2007). By concentrating on direct emissions, the "dense cities" literature places emphasis on the benefits of urban compactness and the accompanying land use patterns which are characterised by economies of scale in building materials and transport options (Bettencourt et al., 2007). However, many studies which confirm the density effect hypothesis do not account for smaller household sizes, higher incomes and more consumption opportunities in cities. These potentially countervailing mechanisms are sketched out in the next subsection.

2.2. Countervailing Effects: Higher Incomes, Smaller Households, More Consumption Opportunities

It is a long-standing observation that urban labour markets allow for greater division of labour, higher productivity and, hence, more competitive wages (Puga, 2010). These characteristics are subsumed in economic research under the heading of agglomeration economies (Krugman, 1991; Glaeser et al., 2001; Rosenthal and Strange, 2004). Larger incomes in cities may increase consumption and therefore the emission of GHG elsewhere in the production chain that are then to be accounted for as "indirect emissions" — in contrast to the "direct emissions" from household production which usually include the GHG emissions embodied in fuels for domestic energy and private transport (Munksgaard et al., 2000).

However, larger incomes earned in cities are not necessarily spent there. If commuting is easy and comfortable, people may live in smaller municipalities at some distance from the cities' centre, an effect called suburbanisation (Siedentop, 2008 gives a comprehensive review for Germany). Wealthier people may specifically prefer a suburban way of living which offers more single-family residence opportunities. Since in consumer surveys incomes are attributed not to the place where they are generated but to the households' places of residence, under conditions of stronger suburbanisation we may expect higher incomes in wealthy suburbs and not necessarily in the cities themselves. This is especially true in more densely populated regions or countries, as smaller distances and a more highly developed road system may facilitate commuting, whereas in sparsely populated regions distances are usually longer and the road system less convenient (Kenworthy and Laube, 1999). We therefore expect an income advantage of cities over the countryside in thinly populated spaces while the opposite tendency should be observed in more densely populated regions.

In suburbs or rural communities we usually find larger families. Individualisation and singularisation mainly blossom in urban milieus. As a consequence, smaller households are prevalent there, a long standing observation of urban research (Wirth, 1938; Alonso, 1964; Becker, 1981; Glaeser, 2011a). Yet, per capita living costs are higher for smaller households (Hagenaars et al., 1994). This scale effect on the household level is usually accounted for by assigning different weights to household members (e.g. OECD equivalence scale). Smaller households are burdened with higher production costs since many tools and installations are needed only once per household. As a result, smaller households may shift a larger part of their available income to consumption expenditures and/or spend it on more carbon-intensive goods such as heating fuels. Therefore, we expect higher per capita emissions in smaller households (Gough et al., 2011; Underwood and Zahran, 2015; Schubert et al., 2013).

Additionally, the urban context could allow for more attractive consumption opportunities. Some of the literature exploring this suggestion points to an increased footprint in cities (Heinonen et al., 2013a). Thus, beyond increased buying power, agglomeration is also likely to change consumption in relation to overall lifestyle patterns (Glaeser et al., 2001; Heinonen et al., 2013b). More sophisticated consumption opportunities in cities could imply that more of the (higher) disposable income is spent and therefore less money put aside for "savings and private insurances". Furthermore, expenses may also shift towards more carbon-intensive goods and services. For example, nearby airports may seduce urban dwellers to travel long distances more frequently (Lenzen et al., 2004; Holden and Norland, 2005). On the other hand, higher apartment rents (per square metre) absorb some of the disposable income and reduce its otherwise possible expenditure on more carbon intensive goods. In balance, we expect spending to be more carbon-intensive in cities than in rural areas.

2.3. Regressive Impact of Rising Energy Prices on Rural Households

Domestic energy is usually seen as a basic need with low income

elasticities according to the theory of Engel curves, similar to food (Chai and Moneta, 2010; Schulte and Heindl, 2017). The same may be true for gasoline in rural regions where public transport is rare or not available. Households that have to spend a larger share of their budget on energy are burdened disproportionally by rising energy prices. Energy taxation for environmental reasons has the same regressive effect, at least if no compensation is given to the poorer households (Ekins et al., 2011). In Germany, the revenue from the so called "ecotax reform" introduced in 1999 is used to subsidise non-wage labour costs with the aim of making the German workforce more competitive in the global labour market (Bosquet, 2000; Habla and Roeder, 2013). However, German workers in industry sectors which compete in the global arena are usually relatively rather well off (and well organised in the unions) whereas people in service occupations or without employment do not profit in the same manner. Subsidies for regenerative energies are put on top of electricity prices for private households to incite them to use electricity more efficiently (Strunz, 2014; Gawel et al., 2015). As a consequence we expect rural households to be impacted disproportionately — if the density hypothesis proves to be true and even more so if incomes are lower in rural communities.

3. Data and Methods

To estimate an individual's overall carbon footprint, we use a consumption-based approach, with the advantage of including indirect emissions from goods and services (Munksgaard and Pedersen, 2001; Peters, 2008). Thus, "grey" GHG emissions implied in imports are attributed to the demand side (i.e. the wealthy countries), and not to the exporting countries. In this way we avoid the recent global GHG burden shifting towards raw material and bulk commodity exporters such as China which is the result of the usually used production based method of GHG accounting (Schubert and Gill, 2015). We use the current official household expenditure survey for Germany (EVS) and draw carbon intensities of consumption categories from environmentally extended input-output (EE-IO) analysis published by scientists at the German Federal Statistical Office (Mayer and Flachmann, 2011). Similar models have been used since the early 1970s (Bullard and Herendeen, 1975a) and have been applied to a variety of questions relating to lifestyle impacts on energy requirements and associated GHG emissions (for an overview cf. Wiedmann, 2009; Wiedmann et al., 2007). Our approach follows the general line of accounting described in Munksgaard et al. (2000) and Wier et al. (2001). GHG emissions per unit of final consumption are calculated using monetary transactions between sectors together with multipliers of direct energy use and emissions in each sector. The method reallocates energy use and emissions from production sectors where they occur to the final consumption of goods and services, including indirect contributions from an unlimited number of upstream production activities (Nässén, 2014). General issues that arise in combining data from household expenditure surveys with EE-I/O tables are discussed in detail e.g. in Hertwich (2005) and Lenzen (2001).

Data about the consumption patterns of households come from the German income and consumption survey (Statistisches Bundesamt, 2015). At the time of writing in late 2016, the latest fully available version was based on data collected in 2013. Our scientific-use file of the EVS sample contains 42,792 observations, including households' socio-economic and geographical characteristics, detailed information about purchases on standardised consumption categories and different income categories, reported separately for each household member (Statistisches Bundesamt, 2013). To avoid bias that arises from apartment rental price differences between regions, we replaced actual payments with figures using information about each household's living space multiplied by average square metre prices (following Ala-Mantila et al., 2014).[1]

Information about GHG coefficients are derived from data about aggregate emissions and consumption expenditures for the year 2010, provided by the Federal Statistical Office in a highly processed form (Mayer and Flachmann, 2011). By combining I/O-tables containing energy flows and associated GHG emissions for 72 sectors of final demand, a composition matrix and tables with GHG coefficients of the form ε_i = kg CO_2eq / € for 44 consumption categories can be obtained (cf. Wier et al., 2001). The matching of the GHG coefficients with household expenditure is straightforward since all data follows the system of national accounts and the accompanying "Classification Of Individual Consumption by Purpose" (COICOP).

Many studies ignore emissions from government expenditures and gross capital formation as those categories are not treated as "private consumption" in the official national account (Bullard and Herendeen, 1975b).[2] By therefore excluding around 20% of all emissions, existing saving effects — particularly of direct emissions by density effects — might be overestimated to some extend (Gill and Schubert, under review). To avoid such misrepresentation, we include GHG emissions from government and capital formation (Mayer and Flachmann, 2014; Mayer et al., 2014; cf. Erickson et al., 2012; Hertwich, 2005; Jackson et al., 2006; Peters and Hertwich, 2004). Since more detailed information is not available, government-related impacts are distributed equally on a per capita basis, whereas emissions from capital investments are distributed equally to each monetary unit spent (Minx et al., 2013). CO_2 equivalents, such as CH_4 and N_2O from agriculture, are attributed to food and a surcharge for higher impact is accounted to air travel. These procedures help in approximating real environmental impacts from lifestyles. Of course, this shall not imply that consumers were responsible for those expenditures. In a heavily globalized economy, "responsibility" is distributed widely among many actors and processes — resource extraction, infrastructure, production and consumption (for an extensive discussion see Steininger et al., 2014, 2015). The attribution of all emissions to final consumption should only avoid overstating the relative effect of direct GHG savings in the whole picture: with our procedure, gross capital emissions add more to the impact of indirect emissions since more money is spent on this category than on privately consumed fuels which account for the direct emissions. Benchmark values are provided in Davis and Caldeira (2010), Jones and Kammen (2011, 2014), Gough et al., 2011 and in footprint calculators (Schlumpf et al., 1999).

The difference between disposable income and consumption expenditures is rarely discussed in carbon footprint literature. In the German income and expenditure survey from 2013, the consumption expenditures only account for 76.9% of the disposable income whereas diverse non-consumptive spendings, which we aggregate under the headline "savings and private insurances", make up for the rest (23.1%). Savings and insurance have the function to equalise household incomes over time — part of the higher income today is saved to compensate for possible lower income tomorrow.[3] In addition to this inter-temporal stabilisation, we also observe "charity contributions" as a minor part of non-consumptive spendings: membership fees, gifts, donations, et cetera. Whomever that non-consumptive money is given to — banks, insurances, or charity organisations — in consumption

[1] Otherwise, in regions with high rental prices, it would seem as if more GHG would be emitted by this sector than is actually the case. Average square meter prices are calculated from the EVS itself.

[2] National GDP accounts have – in the consumption perspective – three main sheets: for private final consumption (around 60% of the German GDP in money terms), for government final consumption (≈ 20%) and for gross capital formation (≈ 15%). "Government consumption" is measured by the expenditures for the goods which are provided by the state such as education, police, administration etc. "Gross capital formation" is the investment which is used to maintain or expand the capital stock (machines, buildings etc.). The consumption sheet for non-profit organisations and for the building of stocks is also part of the overall national expenditure, but of minor importance here.

[3] The classical example would be the acquisition of an apartment during one's working life to save rental costs when retired. According to the life-cycle permanent income model, first formulated by Modigliani and Brumberg (1954), people try to uphold a certain level of income over their lifespan, or, with an even longer horizon in mind, also to bequeath to their descendants (Friedman, 1957: 20ff.).

perspective it reappears in one of the final consumption sheets of the system of national accounts. Since we have already included all national consumption — private consumption, gross capital formation and government—in our calculation with the procedure described above, we attribute zero emissions to "savings and private insurances" in order not to account for their carbon effects twice.[4]

Dependent variables in this study are per capita carbon emissions for different categories. Urbanity, the centrally discussed independent variable, is indicated by the number of inhabitants, classified by five categories from < 5000 inhabitants ("villages") to > 500,000 inhabitants ("metropolis"). Other independent variables are household size, disposable income, number of cars, living space, consumption expenditure; all of them in per capita terms. Income elasticities (ε) are obtained by the usual log/log regressions: $\ln(y) = \varepsilon * \ln(x) + con + E$, with the specification that we control for household size.

Results from ordinary least squares (OLS) regression analysis rely on several assumptions. Normality of distributions was checked beforehand and living space accordingly log-transformed. Heteroskedasticity is controlled for by calculating with robust standard errors in each regression. Multicollinearity was checked by calculating variance inflation factors (VIF) after each regression and only using those with VIF values lower than 2.5 for single predictors. Since the main interest is to identify mediators, a small amount of multi-collinearity is expected to remain. A lot of attention in regression analysis is paid to outliers, potentially distorting the slope and intercept of the regression line. We adopted the method applied by Büchs and Schnepf (2013) who used similar data for their study of household carbon footprints. Therefore, we first excluded the 1% of households with the highest/lowest incomes and emissions respectively. Afterwards, we ran each regression predicting studentized residuals and excluded all observations with values larger than $|3|$. Results were not substantially affected overall or for any explanatory variable by this or other outlier exclusions. To adjust for representation bias due to the survey design, we used weights provided by the Federal Statistical Office in each calculation (Kühnen, 2001). Due to some representation bias in the EVS, for instance high-income households, figures can be expected to be underestimated as the extrapolated consumption expenditure from the EVS only accounts for 85% of the aggregated consumption expenditure reported in national accounts for the same year.

4. Results

We first give a comprehensive overview of GHG emissions from different consumption categories as well as their respective elasticities in relation to disposable income. Thereafter, we go into more detail by analysing the three questions sketched out in part 2: How strong is the density effect of larger municipalities? How strong are the counterbalancing effects (higher incomes, smaller households, consumption opportunities)? Finally, is there a specific vulnerability of rural communities for rising energy prices?

4.1. Overview: GHG Emissions from Different Consumption Categories

Table 1 illustrates the composition of the individuals' carbon footprint by showing per capita emissions and carbon intensities for different consumption categories as well as income elasticities of emissions and shares of expenditures. Income elasticities were calculated by log/log OLS regressions as outlined above, controlling for income and household size. COICOP consumption categories were merged into eight groups according to similar intensities and elasticities, as well as with respect to functional coherence.

In total, we find an average carbon footprint of 11.4 t CO_2eq annually. The largest single share comes from direct emissions from heat, electricity and fuel consumption, together accounting for about 43% of total emissions. By contrast, only 8.1% of disposable income goes to these categories, highlighting their high carbon intensity. Noticeable by contrast is the high share of expenditure for apartment rents: one fourth of disposable income is spend on the consumption class with the lowest carbon intensity. Overall, the indirect emissions which are included in the purchase of goods and services account for 52% and government expenditures for 5% of total emissions. These observations compare well to other studies' findings, with the most important categories being housing, transport and nutrition, and in its seemingly stable pattern over time (Herendeen and Tanaka, 1976; Weber and Perrels, 2000; Cohen et al., 2005; Lähteenoja et al., 2008).

Relatively low income elasticities for domestic energy, food and communication demonstrate that the categories can be considered generally as "basic needs" according to the theory of Engel curves (Chai and Moneta, 2010). Some of the indirect categories show income elasticities higher than 0.5, but since many heterogeneous items are grouped together, no category fulfils the definition of "luxury" (with $\varepsilon > 1$). Only the category of "savings and private insurances", with $\varepsilon = 1.82$, absorbs a disproportionately high share of the higher incomes, but to a certain extent this can be attributed to the survey design: respondents report their income and expenditure over a period of three months. Seasonal incomes may be high in one period (e.g. for self-employed), but a large amount of this income has to be saved for consumption during the rest of the year.

4.2. How Strong is the Density Effect of Big Cities?

From the theoretical discussion above, we assume that urbanity leads to savings in housing and transport emissions. In Fig. 1, we compare average per capita carbon footprints that are separated into direct emissions from housing and fuel expenditure, indirect impacts of goods and services, and government emissions across municipality type. Results show that overall carbon footprints differ by around 13% between villages below 5000 inhabitants and cities with 100,000 to 500,000 residents. An increase in municipality size shows a clear pattern of a decrease in direct emissions and a rise in indirect emissions. The largest differences exist in emissions from private car use, which amount to more than one ton difference annually.

We looked further at this discrepancy using standard OLS regression analysis. Five models were calculated, adding explanatory variables in a step-by-step procedure (Table 2). The focus lies on the effect of municipality size and how coefficients and explanatory power changes by adding variables believed to function as mediators between the explanatory variable "municipality size" and the dependent variable "per capita direct emissions". Model 1 essentially restates Fig. 1. As the β-coefficient of the "metropolis" dummy variable indicates, direct emissions in big cities are 35% lower than in the reference ("village"). Model 2 and 3 show that this saving effect mainly results from living area and number of cars per person, or—more directly—from corresponding domestic energy and gasoline expenditure.[5] Including these control variables, the difference between cities and villages is strongly reduced. The remaining 4% difference in Model 3 are probably due to more compact and better insulated buildings (Weber and Gill, 2016) and heating fuels with lower carbon intent (district heating and gas in contrast to heating oil which prevails in the countryside). Additionally, Model 4 and 5 demonstrate the saving impact of household size and the boosting impact of disposable income on direct GHG emissions—these controls increase the difference between metropolis and village.

The analysis shows the persistent importance of direct emissions to

[4] Chitnis et al. (2014) have attributed UK average intensity GHG emissions to savings (0.57 kg CO2eq/£), but without explicit discussion.

[5] In Model 3, the number of observations is reduced due to the fact that 1146 households report zero expenditure for domestic energy and 7245 households report zero expenditure for gasoline. By the log procedure they are transformed to missing.

Table 1
GHG (CO_2eq) emissions per person and year from different consumption categories.

Category – COICOP no.	GHG emissions in kg/pp	GHG intensities in kg/€	Income elasticity ε	Share of disposable income
Direct emissions	4894	2.91	0.37	8.10%
Domestic energy (heating fuels, electricity) – C045	3124	3.20	0.25	4.9%
Private transport (gasoline) – C072	1770	2.79	0.46	3.2%
Indirect emissions	5973	0.42	0.58	68.8%
Food (incl. alcohol + tobacco) – C01 + C02	1597	0.74	0.26	10.6%
Dwelling (rent, repair, furniture) – C041-C044 + C05	1491	0.27	0.51	25.5%
Recreation, culture, hotels, restaurants – C09 + C11	1172	0.37	0.66	12.3%
Transport (indirect + public) – C071 + C073	877	0.57	0.84	7.5%
Clothing, health, miscellaneous – C03 + C06 + C12	667	0.30	0.87	10.1%
Communication, education – C08 + C10	169	0.29	0.30	2.8%
Government	550			
Sum or average of consumption expenditures	11,417	0.71	0.56	76.9%
Savings and private insurances	0	0.00	1.82	23.1%

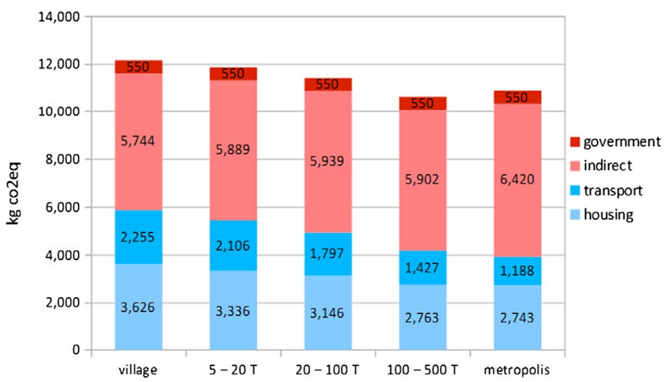

Fig. 1. GHG emissions per capita according to municipality size.

measure total carbon footprint. The density effect can be confirmed for direct emissions, specifically for cities between 100,000 and 500,000 residents. Higher income levels and household composition are further considered in the next sections.

4.3. Counterbalancing Effects

As Fig. 1 already shows, indirect emissions are higher in metropolises than in villages. In Table 3 we further analyse this effect by running a standard OLS-regression, similar to the former (cf. Table 2), but now on indirect GHG emissions. Model 1, again, essentially tells us the same information as Fig. 1. Indirect emission are augmented by 9.6% in big cities in relation to the reference ("village"). Interestingly, this effect results not only from higher disposable incomes, but from different household sizes and larger consumer expenditure in cities. As

Table 2
OLS regressions on direct GHG emissions per capita (log).

DV: direct GHG (log/pp/kg)	Model 1	Model 2	Model 3	Model 4	Model 5
Municipality size 2	− 0.0608***	− 0.0319**	− 0.0174***	− 0.0853***	− 0.0881***
(5–20 T inhab; ref: village)	(− 4.92)	(− 2.97)	(− 3.99)	(− 7.18)	(− 8.03)
Municipality size 3	− 0.142***	− 0.0560***	− 0.0279***	− 0.191***	− 0.169***
(20–100 T inhab; ref: village)	(− 11.73)	(− 5.39)	(− 6.36)	(− 16.36)	(− 15.72)
Municipality size 4	− 0.296***	− 0.126***	− 0.0441***	− 0.371***	− 0.317***
(100–500 T inhab; ref: village)	(− 21.60)	(− 10.78)	(− 8.39)	(− 27.63)	(− 25.75)
Metropolis	− 0.353***	− 0.128***	− 0.0422***	− 0.445***	− 0.418***
(> 500 T inhab; ref: village)	(− 26.09)	(− 10.93)	(− 7.21)	(− 33.36)	(− 33.38)
Apartment space		0.432***			
(log/pp/square meter)		(54.94)			
Number of cars		0.555***			
(pp)		(58.36)			
Domestic energy expenditure			0.558***		
(log/pp/€)			(153.72)		
Gasoline expenditure			0.382***		
(log/pp/€)			(117.53)		
Household size				− 0.136***	− 0.0734***
				(− 43.86)	(− 24.21)
Disposable income					0.488***
(log/pp/€)					(70.08)
Intercept	8.455***	6.365***	2.260***	8.777***	3.854***
	(846.38)	(213.88)	(93.26)	(695.67)	(53.80)
N	41,417	41,417	34,120	41,417	41,417
Adj. R^2	0.035	0.322	0.848	0.088	0.229
Max VIF/mean VIF	2.30/2.08	2.31/1.80	2.10/1.59	2.32/1.89	2.32/1.77

t-statistics in parentheses.
* $p < 0.05$.
** $p < 0.01$.
*** $p < 0.001$.

Table 3
OLS regressions on indirect GHG emissions per capita (log).

DV: indirect GHG (log/pp/kg)	Model 1	Model 2	Model 3	Model 4
Municipality size 2 (5–20 T inhab; ref: village)	0.0208* (2.42)	0.00399 (0.64)	−0.0102 (−1.74)	−0.0143*** (−5.41)
Municipality size 3 (20–100 T inhab; ref: village)	0.0310*** (3.68)	0.0304*** (4.99)	−0.00243 (−0.42)	−0.00949*** (−3.61)
Municipality size 4 (100–500 T inhab; ref: village)	0.0321*** (3.40)	0.0586*** (8.79)	0.00625 (0.98)	0.00435 (1.46)
Metropolis (> 500 T inhab; ref: village)	0.0958*** (9.89)	0.0778*** (11.18)	0.0175** (2.61)	0.00278 (0.88)
Disposable income (log/pp/€)		0.627*** (159.85)	0.575*** (145.63)	
Household size			−0.0930*** (−56.44)	−0.0114*** (−14.09)
Consumption expenditure (log/pp/€)				0.927*** (416.22)
Intercept	8.504*** (1230.93)	2.372*** (61.32)	3.101*** (77.59)	0.998*** (52.03)
N	41,460	41,460	41,460	41,460
Adj. R^2	0.004	0.498	0.543	0.905
Max VIF/mean VIF	2.30/2.07	2.30/1.86	2.32/1.77	2.32/1.80

t-statistics in parentheses.
* $p < 0.05$.
** $p < 0.01$.
*** $p < 0.001$.

Table 4
Spending on different categories according to household size.

Household size (persons)	Disposable income (€ pp)	Direct energy expenditure (€ pp)	Other expenditure (€ pp)	Total expenditure (€ pp)	Savings and insurances (€ pp)	Savings (pp) per income (€ pp)	Net equivalent income (€)[a]	N
1	22,682	1902	16,704	18,606	4076	18.0%	22,682	14,083
2	21,165	1719	14,722	16,441	4724	22.3%	29,932	17,564
3	17,625	1431	11,445	12,877	4749	26.9%	30,528	5538
4	15,539	1223	9951	11,174	4365	28.1%	31,078	4257

[a] Calculated as household income divided by square root of household size.

the sequence of Models 1 to 4 illustrates, the control for income only reduces the emission surplus of big cities from 9.6% to 7.8%, whereas the additional control for household size decreases it more clearly, i.e. to 1.8%. However, it is important to note that the influence of household size is mainly a result of differences in consumption expenditure: with the control for consumption expenditure, household size influence is strongly reduced and the emission surplus of the big cities vanishes.

As it is visible in the OLS regressions in Tables 2 and 3, household size has a reducing effect on direct as well as indirect per capita emissions. To further elucidate this phenomenon, we show how the different household sizes allocate their income to different spending categories in Table 4. Unsurprisingly, per capita income decreases with household size (resulting from the fact that additional persons often earn less or receive less transfer than the first person in the household). Expenditure incorporating direct and indirect emissions drop accordingly. What comes perhaps as a surprise is that per capita investment into the "savings and insurances" category increases with household size—both in absolute and relative terms.[6] This might be explained by the higher net equivalent income of the larger households—given economies of scale, with the same per capita income they are better off than smaller households.

[6] This explains why in Table 3, by comparing Model 3 and Model 4, the influence (β-coefficient) of household size in the regression is strongly reduced by introducing per capita consumption expenditure as control variable.

Since larger households are more prevalent in smaller municipalities (average household size ranges from 1.77 in metropolis to 2.38 in villages), we may suppose that "savings and insurances" could be higher there. Table 5 shows a somewhat heterogeneous pattern, but in general the expectation holds true: savings in relation to income are larger in the smaller municipalities. The "consumption opportunities" hypothesis is also supported in respect to "total expenditure" and to "flight expenditure". But on the other hand we observe that rents are higher in the cities, resulting in higher expenditure for a less carbon intensive category. In general, the indirect carbon content per Euro spent is lower in the larger municipalities, but with the higher spending, overall indirect emissions are 10% higher in big cities in relation to villages.

The starkest effect however comes from the highly carbon-intensive expenditure for direct energy. Fig. 2 shows how the emissions rise differently with increasing income in villages in contrast to big cities.

As can be expected, direct emissions in smaller communities reach a rather high level, whereas they remain below 8000 kg in big cities. It is however interesting that the direct emissions stagnate at that high level (around 10 tons) in villages; the stagnation level is reached with an annual per capita income of around 55.000 Euro whereas the emissions for the big cities has a more steady incline. The former observation possibly points to a saturation effect (in the sense of the Environmental Kuznet Curve), but it is reached only at an income much higher than the current average of 20,500 Euros. The rise of indirect emissions is rather

Table 5
Spending on different categories according to municipality size.

Municipality size	Disposable income (€ pp)	Direct GHG related expenditure (€ pp)	Indirect GHG related expenditure (€ pp)	Private flight expenditure (€ pp)	Savings and insurances (€ pp)	Rents/imputed rents (€ pp)	GHG intensity of indirect expenditure (kg/€)	N
Village	20,335	2025	13,588	43	4722	4314	0.423	6014
2	20,911	1875	14,273	51	4762	4572	0.413	11,275
3	20,498	1700	14,462	70	4335	4643	0.411	12,281
4	19,580	1459	14,386	77	3735	4606	0.410	7204
Metropolis	21,452	1366	15,759	137	4328	5057	0.407	6018

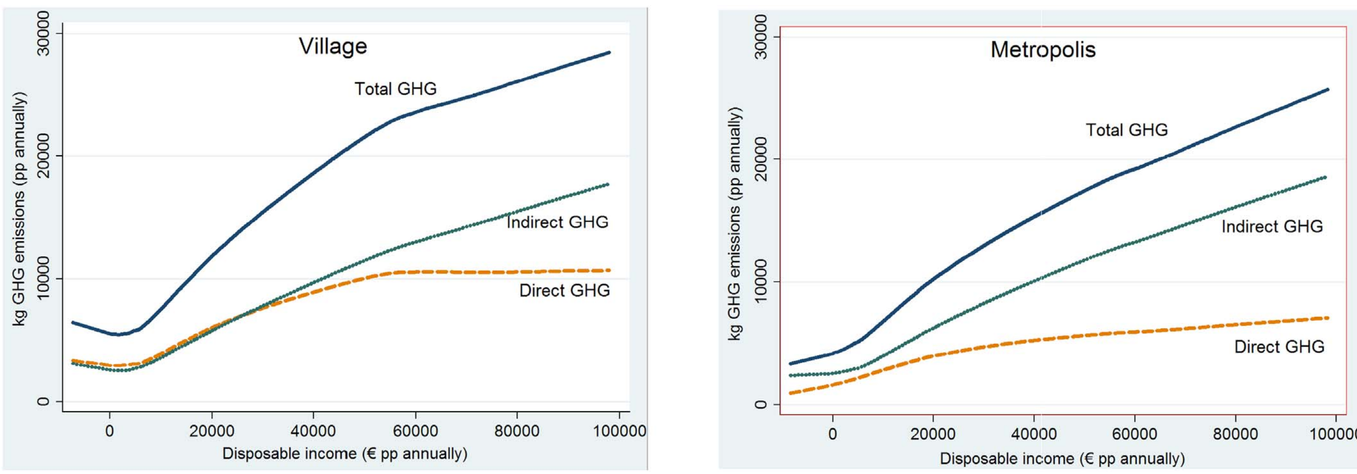

Fig. 2. Rising emissions with increasing income in villages and big cities (indicated by locally weighted regression lines).

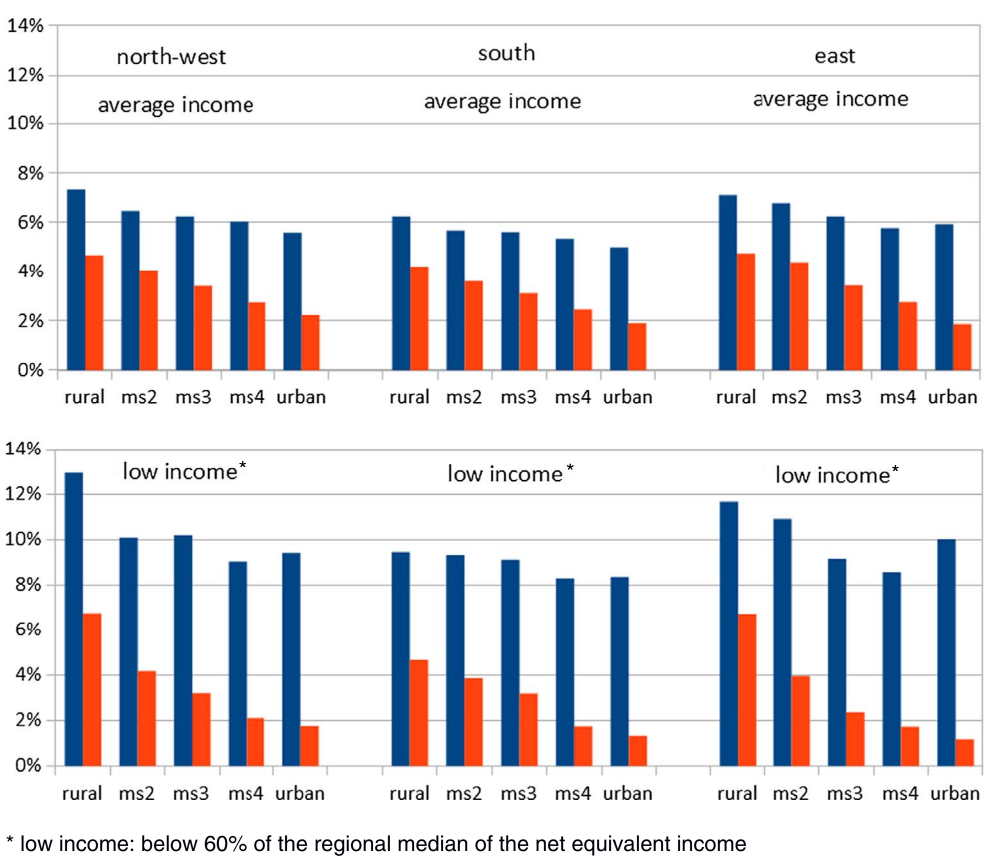

Fig. 3. a and b: Domestic energy (blue/left columns) and gasoline (red/right columns) expenditure as share of disposable income, by municipality size and German region. For all households (3a, above) and for low income households* (3b, below). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

linear over the whole income range and only slightly higher in the cities than in the villages. As a consequence, differences in level and shape of the total emissions line are mainly determined by direct emissions.

In sum, we observe that carbon savings as a result of the density effect of the big cities is somewhat levelled out by higher earnings, smaller household size and higher consumption expenditure, but not overcompensated.

4.4. Vulnerability to Higher Energy Prices in Rural Communities

As expected, rural households show a higher vulnerability for rising energy prices as indicated by the budget share of energy expenditure (Fig. 3). The budget share for domestic energy in villages is elevated by around 25% in relation to the big cities in general, and around 22% for low income households. Differences are more pronounced in the northwest than in the south and the east of Germany. The northwest is the former heart of German industry, rather densely populated (296 inhabitants per km^2) and currently experiencing the "rust belt" phenomenon to some extent. The formerly agrarian south (223 inhabitants per km^2) became the richest part of Germany in the last thirty years due to the rise of new industries. Surrounding the metropolis Berlin, the German capital, the formerly communist east is a rather sparsely populated area (154 inhabitants per km^2). The economic history and geography of the country explains why stove heating is more common in the south and also to a certain extend in the east, as firewood is easier to acquire at low prices in the countryside.[7] In contrast to domestic energy, the rural–urban difference in gasoline expenditures is quite stark. In cities, gasoline consumption for most households appears to be a "luxury consumption" as the spending drops from around 2% share for average households to around 1% share for low income households (the reverse is true for domestic energy: around 5% budget share for average, and around 9% for low income households). In the countryside, budget shares for gasoline reach nearly 5% for average households and nearly 6% for low income households. According to the Engel curve theory, gasoline in the countryside can thus be defined as a "necessary good". Differences to the big city are considerable—average rural households consume the 2.3-fold, low income households the 4.4-fold of their urban counterparts.

5. Discussion

First of all, we have to point to some uncertainties and shortcomings of our results. The first source of uncertainty is the reliability of the different carbon intensities which we have drawn from Mayer and Flachmann, 2014, who are to our knowledge the only source for this data for Germany. Their calculations are based on a hybrid I/O model with regionalisation of imports (see also Mayer and Flachmann, 2011). Discussions about the best accounting methods, particularly for imports, are still under way and therefore differences between results still common (Hoekstra et al., 2014; Steen-Olsen et al., 2016; Steininger et al., 2015). The second source of uncertainty comes from the bookkeeping method of the survey: participants report their expenditure over the course of three months. Rare acquisitions, e.g. the order of heating oil for the whole year, result in artificial variation between households. In the aggregate this does not matter, but standard deviations are elevated. A major shortcoming is the fact that carbon footprint heterogeneity within consumption categories cannot be taken into account (Girod and De Haan, 2010; Narbel and Isaksen, 2014). Therefore, efforts in the direction of "green consumerism" are neglected, at least in the short term. If, for example, a consumer pays twice the price for a purchase with half the average carbon content, the carbon intensity of the money unit spent would be reduced by a factor of four. An individual switch to a regenerative energy provider cannot directly be attributed to the specific household. Its impact would only be observable in the long run by influencing the general energy mix of Germany and the respective intensity factor. The fact that our intensity data are from 2010 could further mean that the indirect emissions are a little overrated since the expansion of regenerative energies and increasing production efficiency result in a slow but steady trend towards decarbonisation. A further problem results from the fact that municipality size is not necessarily a good indicator for rurality or remoteness. With the suburbanisation of settlement patterns, many villages within reach of commuting transport become home to people whose income and consumption style is well connected to the cities and correspondingly rather "urban" (Siedentop, 2008). Municipality size in Germany also descends from regional histories of "Gemeindereform", i.e. the merging of smaller communities into larger ones. Local preferences either for more autonomy or more integration, together with demographic density, result in strong differences between counties: North Rhine-Westphalia has an average municipality size of 45,114 inhabitants as compared to Rhineland-Palatinate with 1767 inhabitants.

Let us now turn to the discussion of the results: why are the differences between cities and villages not greater? The literature that pioneered the "density" approach started with an observation of much stronger effects (e.g. Dodman, 2009; Hoornweg et al., 2011a). This is due to the fact that this strand of research is methodologically mainly based on the urban metabolism approach which is focused on production and not on consumption (as is the carbon footprint analysis used in our study). The urban metabolism approach attributes only those emissions to the city, which directly result from production within the same city's confines (though the citizens of that city as consumers still profit from energy-intensive production elsewhere). Since in developed countries in the last 50 years most of the carbon-intensive and heavy polluting industries have been relocated either to the hinterlands or to low-wage regions in other parts of the world, most cities rank rather low on the production emissions scale. An additional problem arises from the fact, that many studies have focused only on direct emissions and do not put these into relation with the overall emissions which also include indirect emissions, gross capital investment, and government expenditure (cf. for more detail Schubert and Gill, 2015).

Studies using the consumer's carbon footprint method usually reveal only small differences, either in favour off or against emission savings in cities. What are the reasons for the balance to shift in one or the other direction? This article, based on Germany, points to higher emissions in rural areas, while our own follow-up study on Bavaria shows the opposite: higher emissions in cities (Gill and Schubert, under review). With additional studies in our working group regarding other subregions in Germany, we have come to the conclusion that the main reason might be settlement density: in denser settled regions, mainly in the Rhine and Ruhr regions, we find higher emissions in villages because income contrasts do not follow municipality size but tend to be based on regional segregation effects. In the more densely settled regions, lower commuter distances allow the wealthy to settle among themselves—often in small suburban villages. Similar suburban and higher countryside emission patterns seem to prevail in the UK (Baiocchi et al., 2010; Druckman and Jackson, 2009; Minx et al., 2013), whereas in more sparsely populated territories like Australia (Dey et al., 2007), Finland (Heinonen et al., 2013a) and Bavaria (Gill and Schubert, under review), higher emissions are reported for cities while most of the small municipalities are more remote and, therefore, not within reach of wealthy suburban commuters. Here, the traditional contrast between urban and rural is still dominant.

Jones and Kammen (2011, 2014), who in their earlier study reported GHG savings from density for the US, have taken a geographically more elaborated approach in the more recent study by differentiating between urban, suburban and rural locations. They

[7] According to the German building census of 2011, in the north-west 4.5% of all homes have stove heating, 12.9% in the south and 5.1% in the east. Based on results from the firewood heating survey of Mantau (2012: 17), one can calculate that in 2010 in the north-west 0.18 stere, in the south 0.48 stere, and in the east 0.25 stere firewood per capita had been burned.

observe a U-shaped relationship: the cities' cores have lower emissions due to density effects; whereas the suburbs have rather high emissions due to high incomes, large housing spaces and long private transport distances; while the rural locations are on par with the cities' cores due to lower incomes.

China, as an example of a fast developing country, shows a marked contrast between urban and rural regions: in urban regions, incomes are higher and city dwellers have access to modern energy services based mainly on fossil fuels, whereas in the countryside low incomes prevail and energy services are based on biomass (which is normally seen as GHG-neutral). As a consequence, urban households in China emit almost three times more CO_2 per capita than rural households (Feng and Hubacek, 2016; cf. Minx et al., 2011). Plans of the Chinese government to relocate rural residents in large numbers to urban districts will correspondingly result in a huge emission increase.

Much research remains to be done before a consensus on method and results will be reached. But a preliminary summary of the worldwide observations would appear to be that three general mechanisms are shaping the rural-urban GHG emission contrast: (1) The energy transition from biomass to fossil fuels starts initially in the urban centres, increases GHG emissions there and slowly reaches the hinterlands. The planned energy transition from fossil fuels to regenerative sources is too young to evaluate their impact. Given the availability of space for "harvesting" energy directly via solar cells or indirectly via biomass, wind farms or hydroelectric plants from solar radiation, the transition may start in less densely populated areas and thus work in the opposite direction (for a general historical account on land use see Sieferle, 2001). (2) Incomes, influencing GHG emissions indirectly, are usually higher in urban agglomerations than in peripheral areas. But with better transport and communication, differences between urban cores and hinterlands decrease. (3) Density effects are stronger in cities and city districts, which were built at an time when transport was still slow (Kenworthy and Laube, 1999). Based on these three mechanisms alone, strong saving effects in favour of big cities are not foreseeable in the near future.

6. Summary and Policy Recommendations

As we have seen already in Fig. 1, differences in GHG per capita emissions between urban and rural settings are not very large. Cities and rural communities do not differ as significantly in their direct and indirect emissions as it may be expected. Shorter distances, public transport and smaller apartment size reduce direct emissions by 35%, but the on average smaller household size in cities works slightly in the opposite direction.[8] In cities, larger labour markets enhance income generation opportunities for households. With more consumption opportunities, a larger share of the disposable income is spent, but higher apartment rents reduce the emission effect of that spending. Higher incomes and more spending mainly impact indirect emissions which are augmented in big cities by 10% as compared to villages. Overall, direct and indirect emissions counterbalance one another, resulting in a difference of only around 11% between "village" and "metropolis" for all GHG emissions combined. What we observe in these rather small differences is a long way from the International Panel on Climate Change (IPCC) target of a sustainable level of 2.5 t of GHG emissions per capita annually.

The higher per capita direct emissions in the countryside also imply that households there are more strongly impacted by price increases for energy services, which may result from higher producer costs or from environmental taxes. This is particularly true for the purchase of gasoline for private transport, which in cities clearly shows Engel curve features of a "luxury good", while in rural areas private transport figures as a "basic need". In contrast to gasoline purchase, domestic heating seems to be not as exposed to price increases since in many rural regions there exists the possibility to switch to fire wood. Due to this coping possibility, the vulnerability of poor rural households seems to be lower with respect to heating price increases, but this depends on local possibilities and an individual households' capabilities.

What does this imply for policy recommendations? Not too much ecological hope, but also not too much fear should be invested into different settlement patterns, at least not in the crude opposition of "city versus countryside". Future research and planning policies should focus on a more comprehensive understanding of functional dependencies between housing and transport technologies, family models and labour markets. Environmental taxes on domestic energy and gasoline could make urban settlement more attractive in the long run, at least if it reaches a certain strength and would outweigh other factors. But more conceptual effort and empirical research is needed to distinguish between opportunities and preferences: do people live in the countryside because living costs are cheaper there or because they prefer this specific "way of life"? If differences could be traced back to circumstances, then the opportunity structure would be the central policy target. If they were more the effect of different preferences, then the cultural models would be of critical concern (e.g. Cramer, 2016). People who stick to their rural identities and lifestyles, may develop resentments against a change of opportunity structure in favour of urban settlement and strongly resist environmental policies. In many developed countries we can now observe such discourses on the political right which draws its support traditionally from rural and, at present, increasingly from low income voters (e.g. McCright and Dunlap, 2013).

If environmental and social policies were to be combined, carbon footprint studies should not focus on emission quantities and intensities alone, but also on elasticities. Income and expenditure surveys in combination with carbon flow I/O-tables open up a new and fruitful avenue for critical observation.

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[8] For the same household size the reduction of direct emissions in "metropolis" would be 44% (instead of 35%) in contrast to "village".

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